

Beyond TRL: A Revised Model of Technology Development and Considerations for Programmatic Analysis

Prof. Zoe Szajnfarber

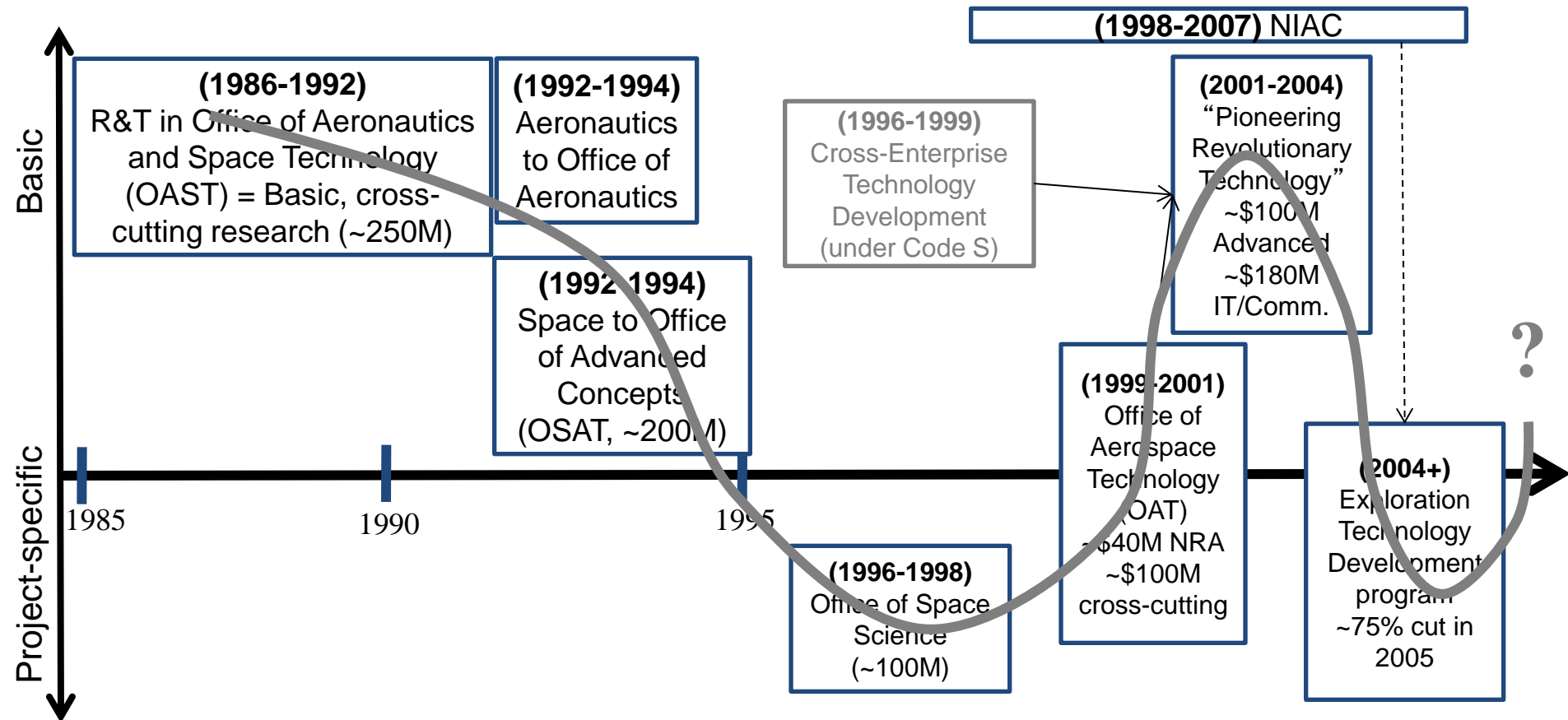
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On Technology Cost Estimating

- Technology development– or the focused long term development of – is a major part of R&D at NASA.
- Technology Cost Estimating is a relatively unexamined field in the academic literature on cost estimating
- NASAs recent efforts to fund technology cost estimating research have been helpful in understanding how technology develops (Cole et al 2013, 2014)
- Our focus is not on technology cost estimating: we study the process of technology development itself
 - However, we hope our research can provide insight for the cost and scheduling community

History of Shifts in R&D Strategy



(Based on data collected for NASA R&T Study and NRC study of NIAC)

NEED: To control the system better, we need to understand it better.

Guiding Research Questions

NEED: To control the system better, we need to understand it better.

1. How do new capabilities traverse the innovation system as they are matured and infused into flight projects?
 - Empirically grounded models of the innovation process
 - Considers technical, social and political factors
 - Can this process be predicted/estimated?

2. To what extent can the process be improved through feasible management interventions?
 - Exploring organization configuration as a design lever
 - Design for evolvability/tinkerability
 - Improved incentive systems, based on valid preference structures.
 - Balanced technology investment strategies that acknowledge key attributes of space innovation ecosystem

NASA Innovation Landscape

Political-level context

Agency-level planning

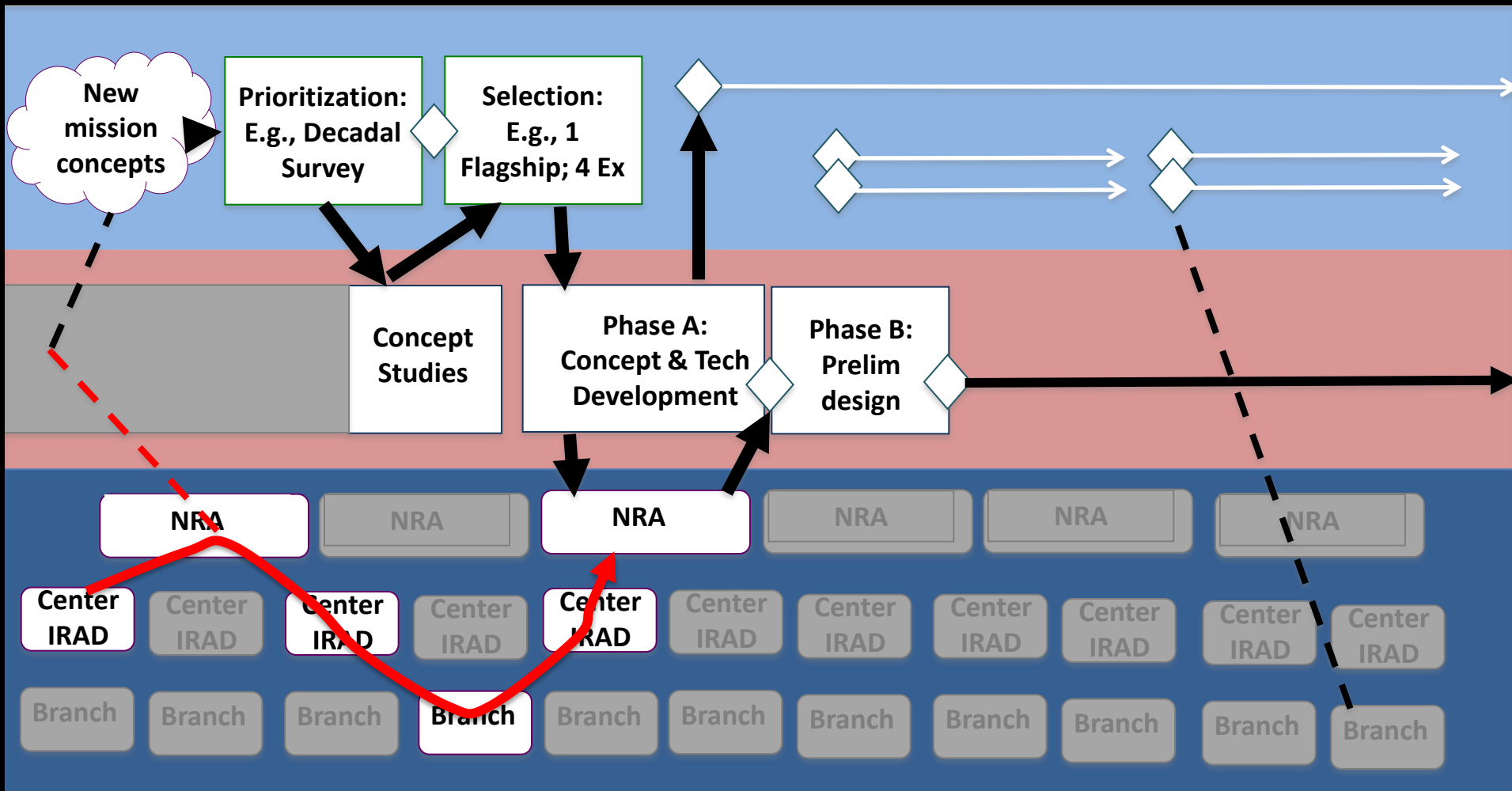
Project-level Development & Implementation

Technology-level Research & Development

Scientific and Technical State-of-the-art

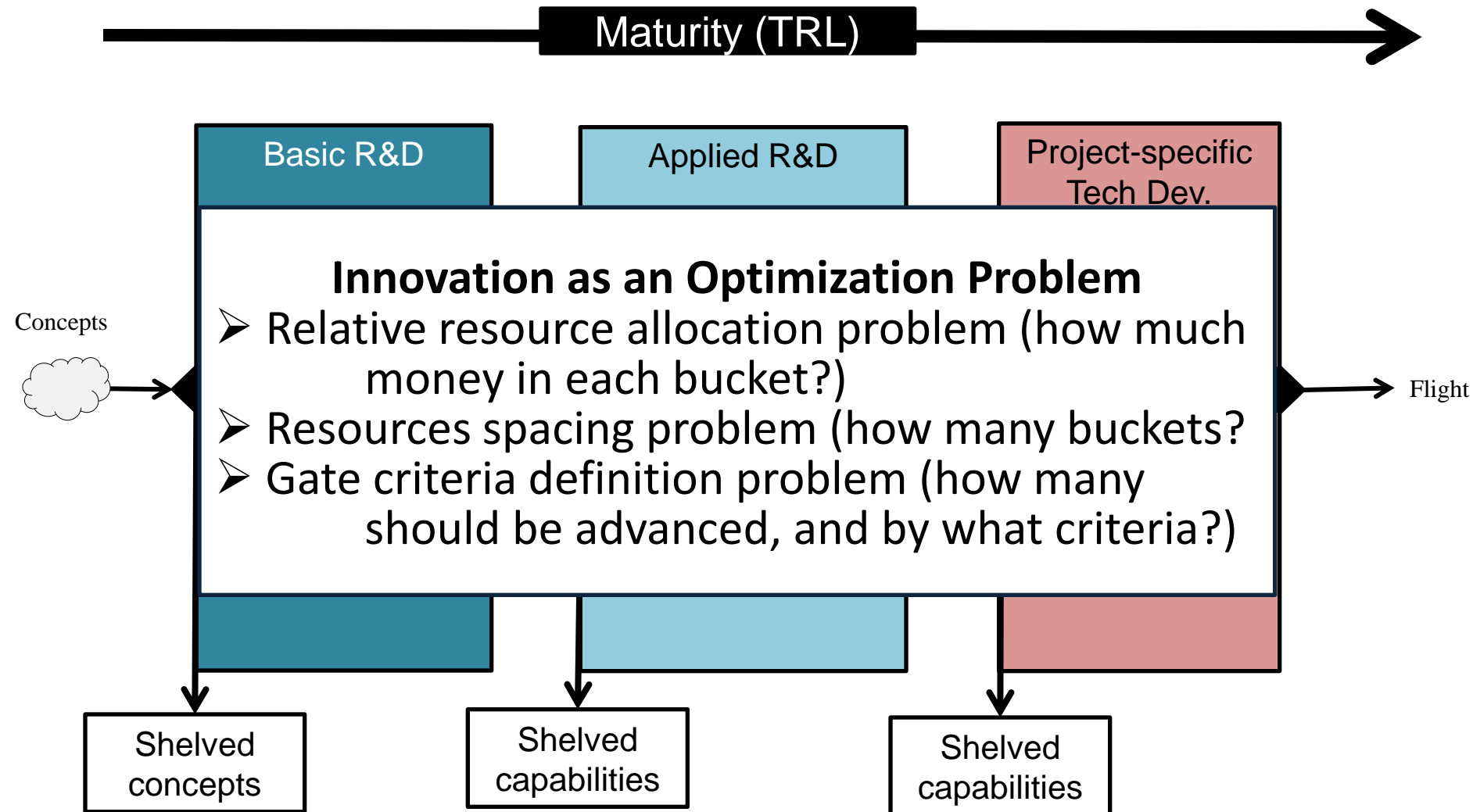
NASA (Space Science) Innovation Landscape

Political-level context



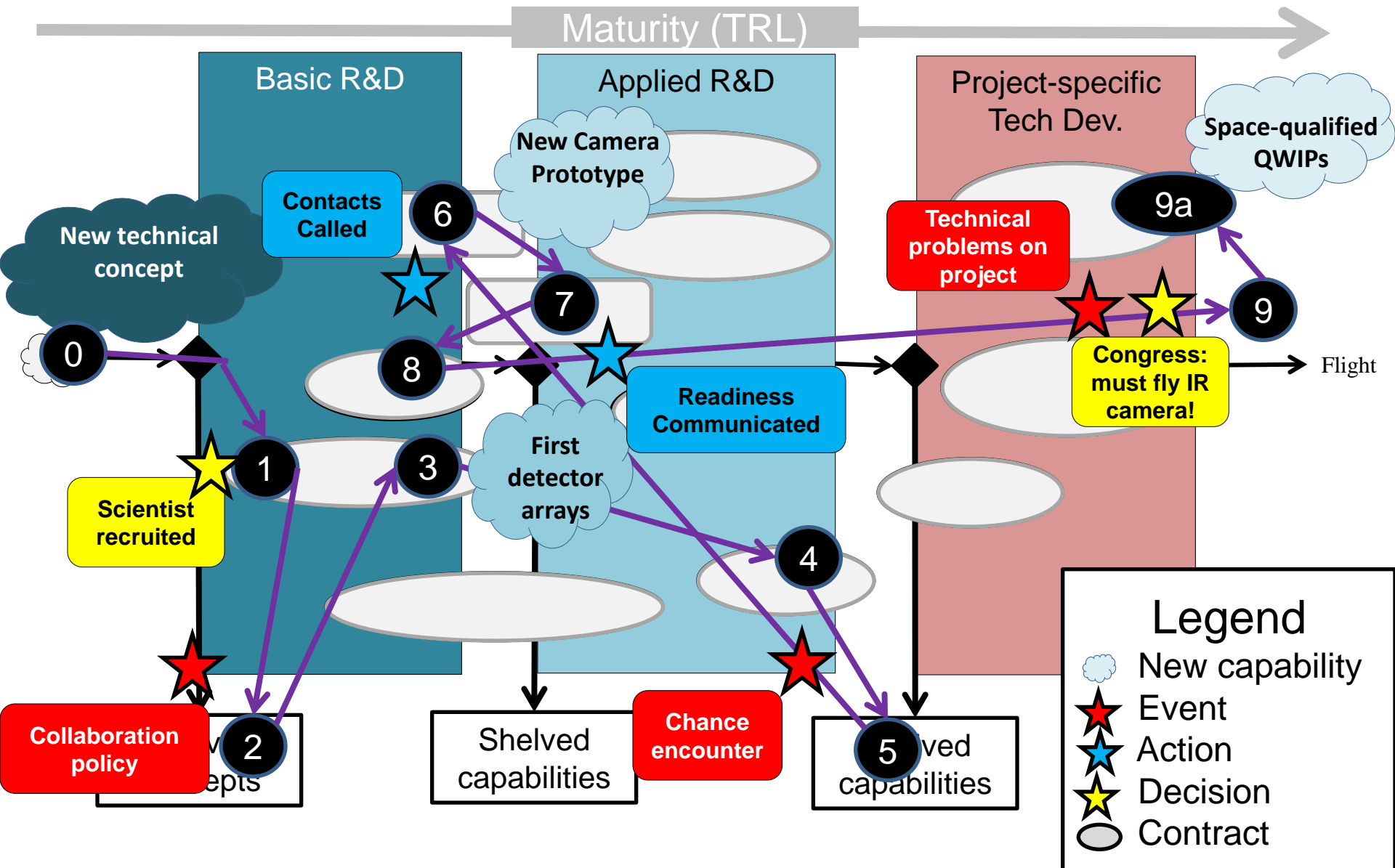
Scientific and Technical State-of-the-art

Current Conceptualization: Stage-Gates

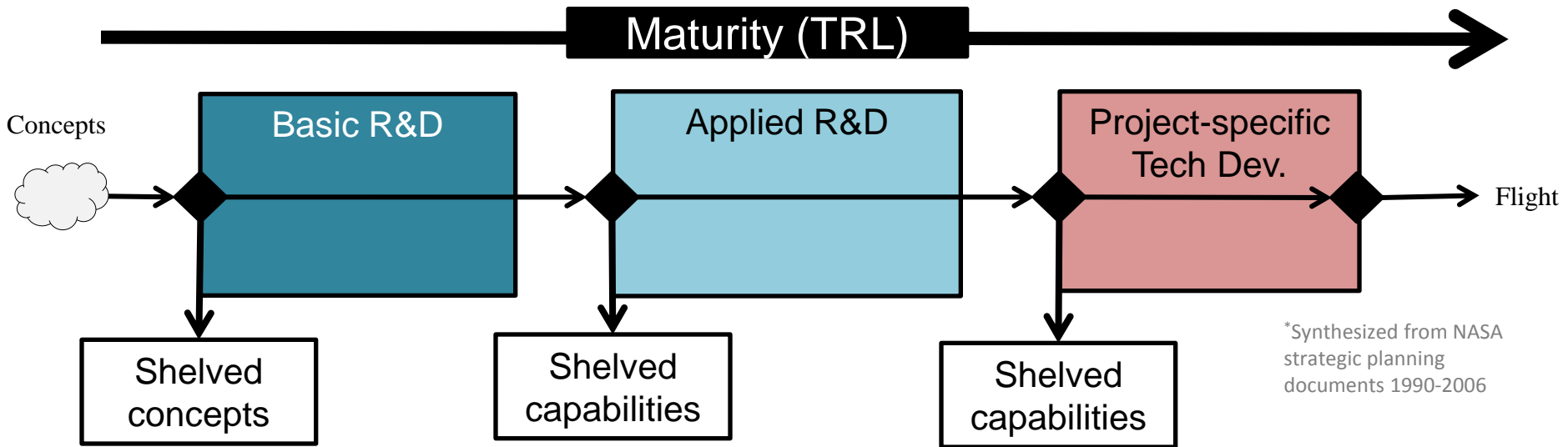


*Synthesized from NASA strategic planning documents 1990-2006

Actual Complexity of Process



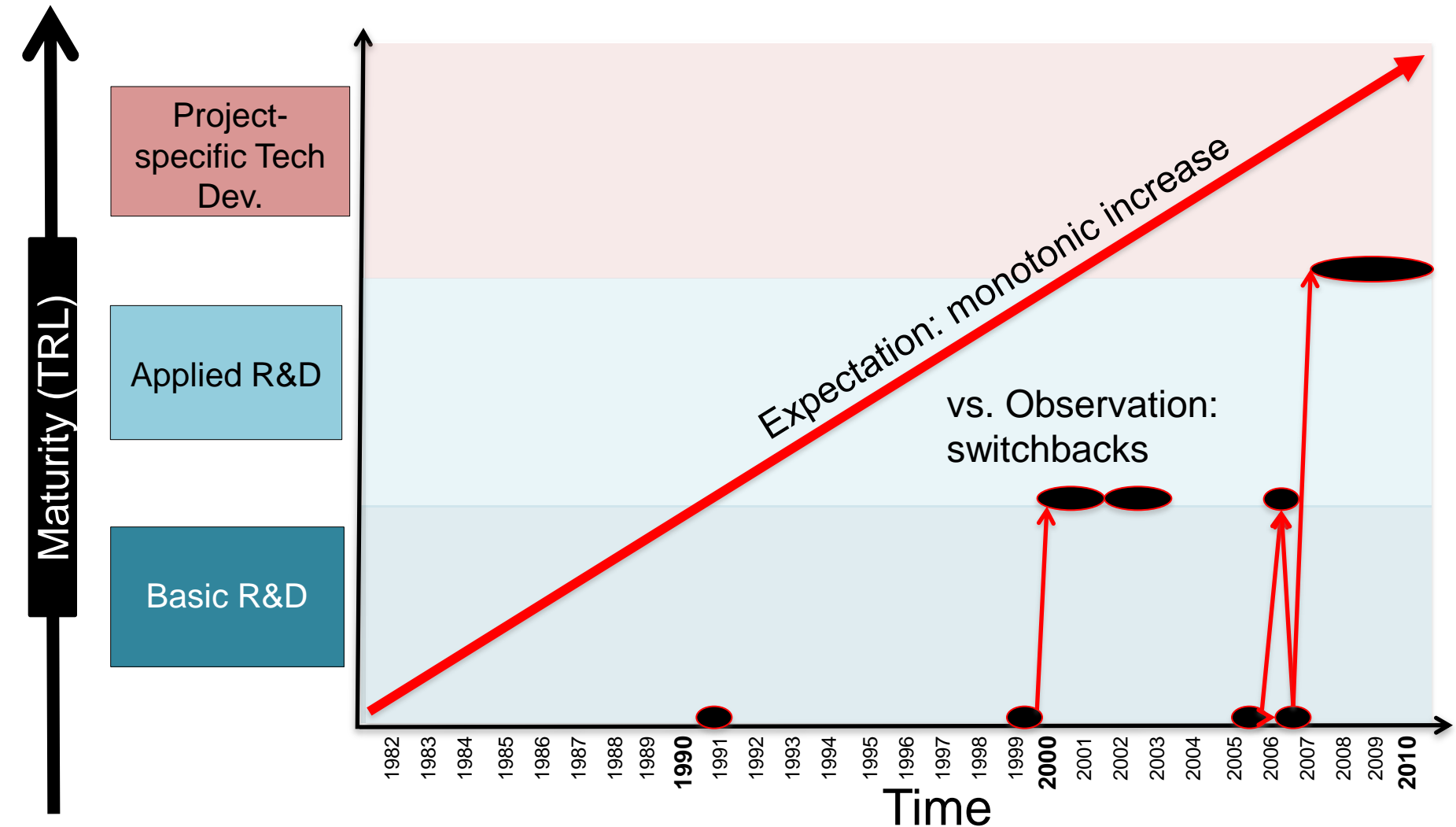
Stage-Gate Assumptions



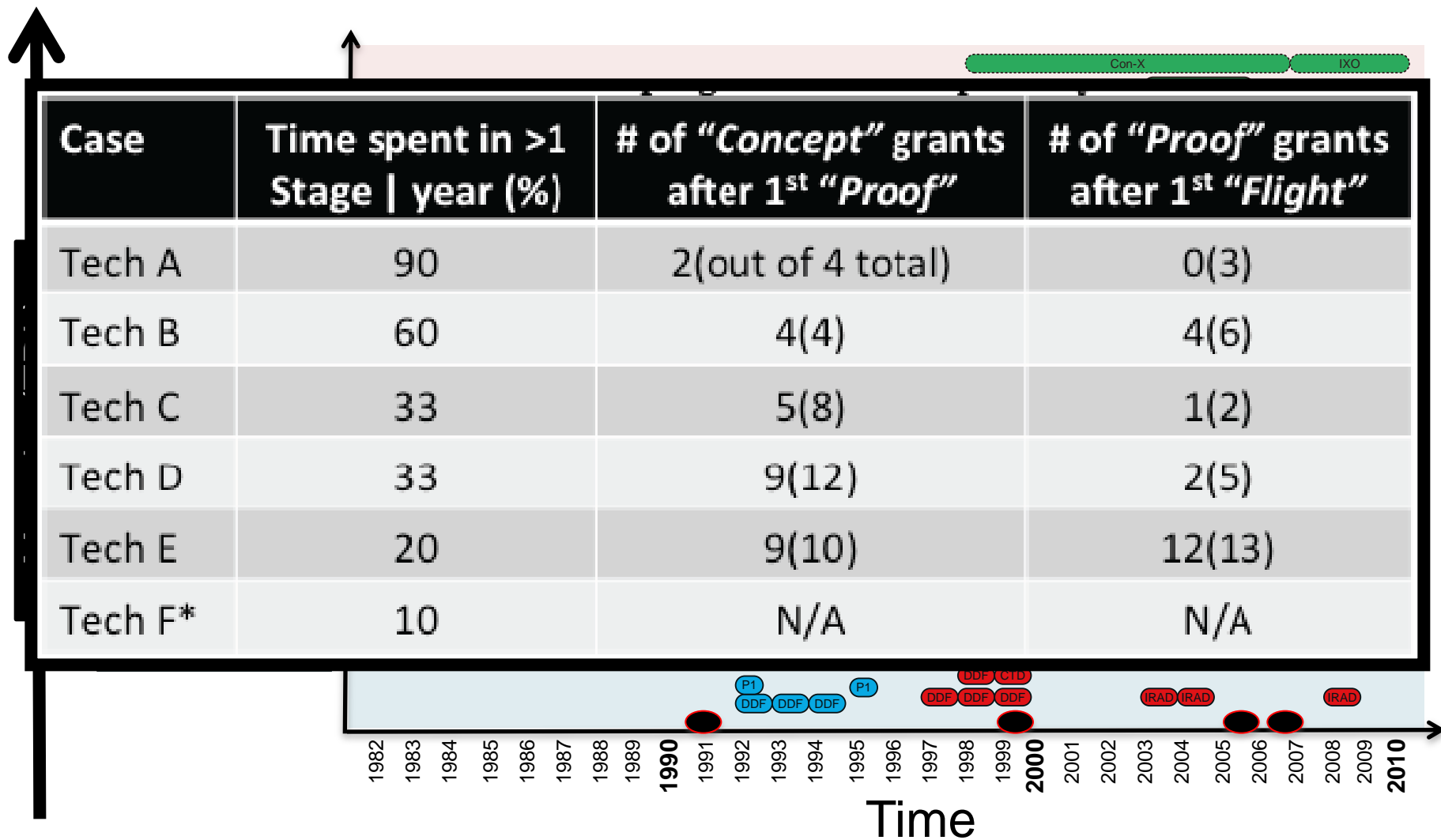
Underlying assumptions:

- (1) Technologies **mature** from left to right over time;
- (2) **Stages** are mutually exclusive (at a given time);
- (3) **Shelving** is an active process, controlled by decision makers;
- (4) **Shelf life** is passive and a function of technical obsolescence.

Switchbacks in Maturity



Switchbacks in Maturity



Passive Gates, Active Shelves

- Expectation (assumptions #3 and 4):
 3. Rejection at Gate => Shelving
 4. Similar shelf lives for similar technologies
- Observation:

Case	Rejected + Shelf	Rejected + !Shelf	!Rejected + Shelf	Duration on Shelf
Tech A	1	1	1	8 /1yrs
Tech B	0	2	1	5 yrs
Tech C	0	3	0	N/A
Tech D	0	2	1	2 yrs
Tech E	1	Multiple	1	2 / 5 yrs
Tech F	0	multiple	0	N/A

Szajnfarder, Z., and Weigel, A. L. (2012). "Managing Complex Technology Innovation: the need to move beyond stages and gates" International Journal of Space Technology Management and Innovation, 2(1), 30-48

Need: More nuanced understanding of underlying processes

Building Theory from Case Studies

Process Data

Within-case

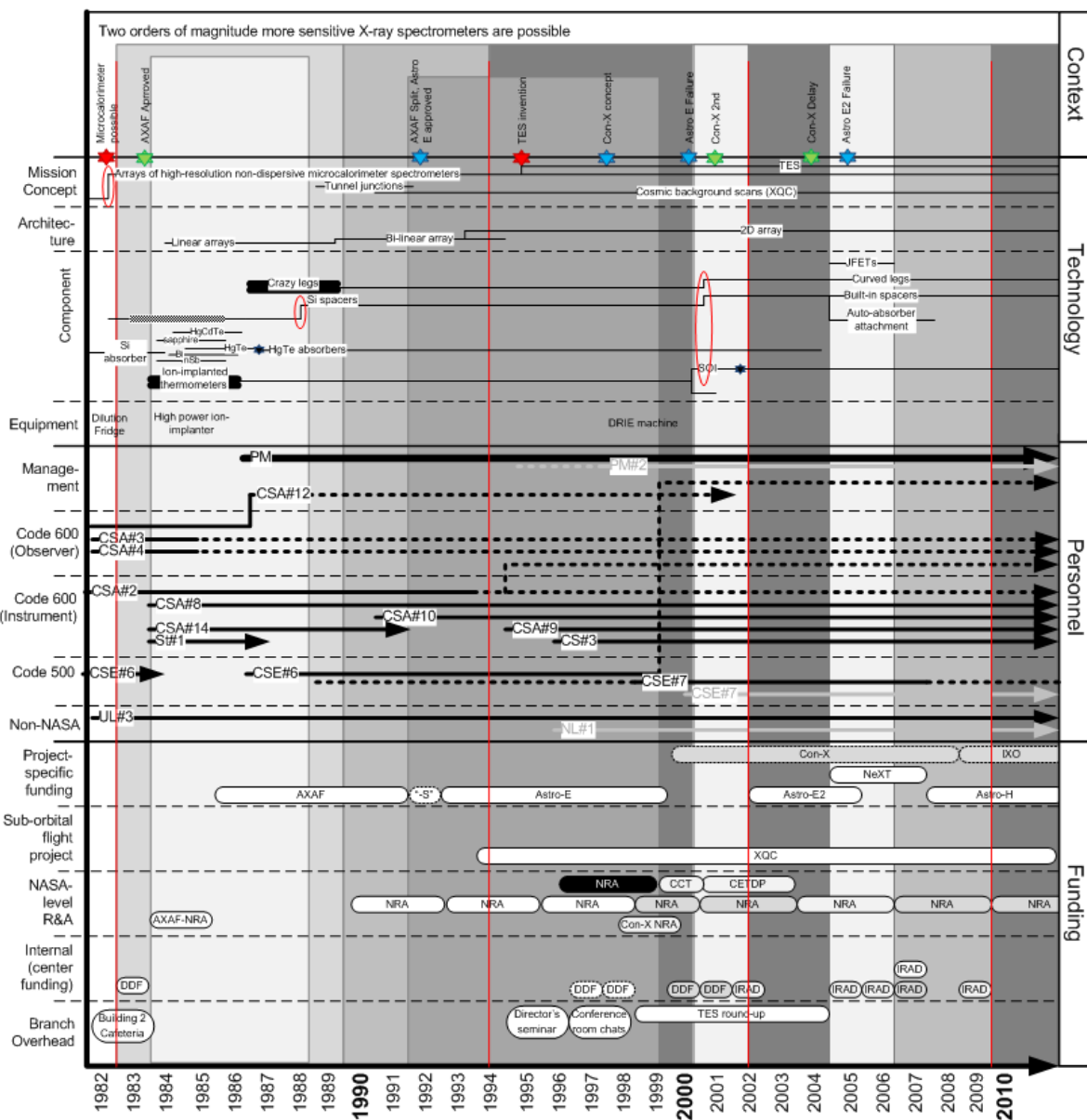
Analytical Chronologies (Pettigrew 1990)

~100 hrs
interviews

~150
archival
documents

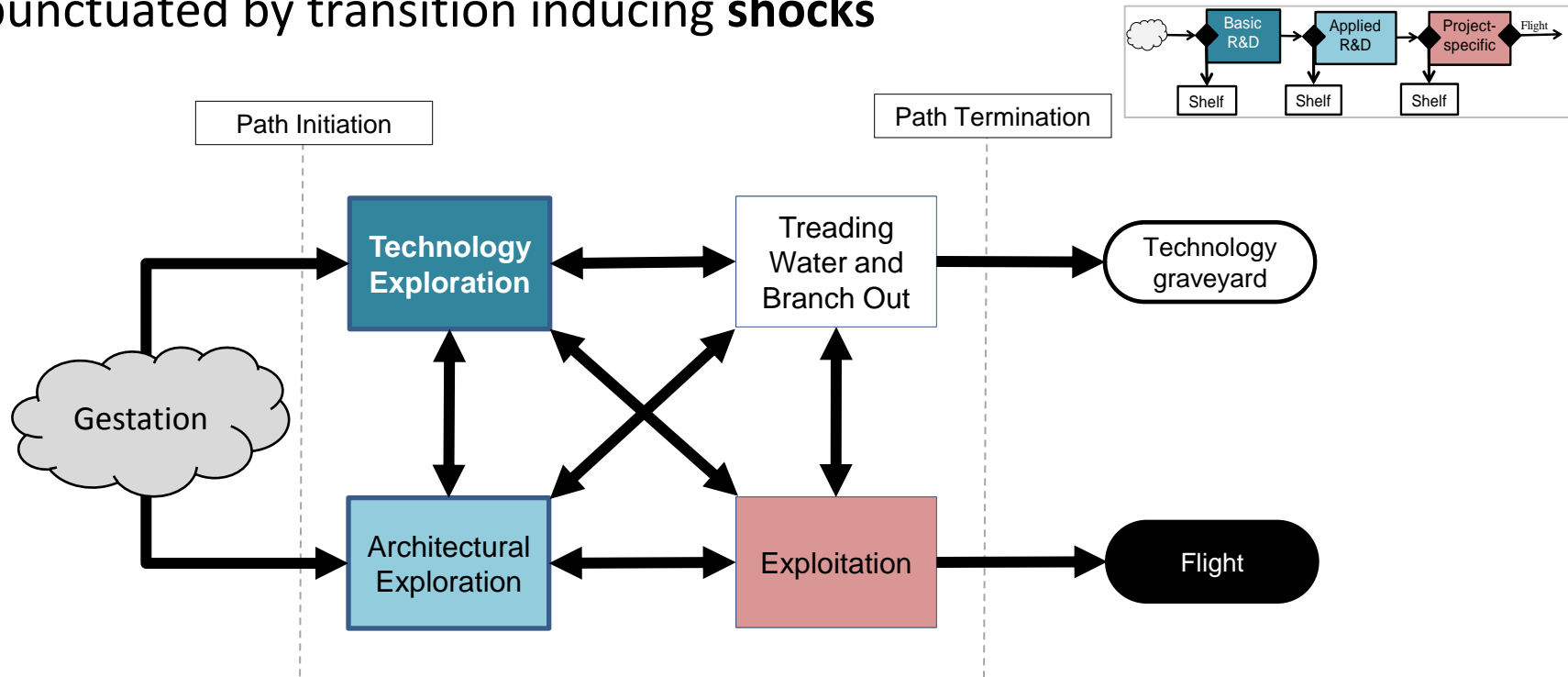
~2 months
informal
observation

Event Database
(Van de Ven et al
1990; 2000)



Epoch-Shock Model: Track View

- System exhibits **epochs** of persistent stable (and identifiable) behaviors punctuated by transition inducing **shocks**

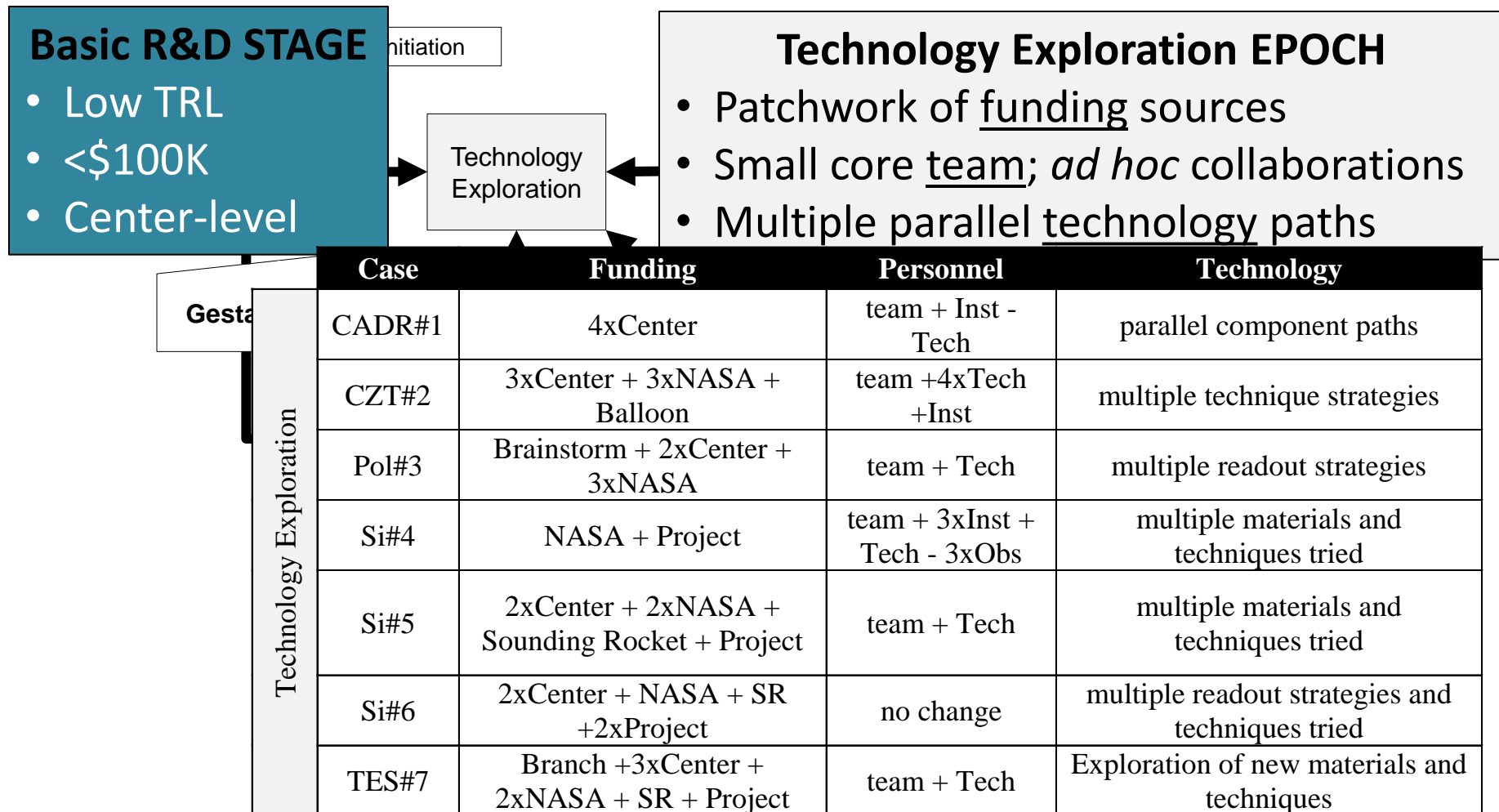


- **Epochs** are illustrated as boxes, and roughly map to stages
- **Shocks** induce transitions following arrows from one box to another

Szajnfarder, Z., and Weigel, A. L. (2013). "A process model of technology innovation in governmental agencies: insights from NASA's science directorate" *Acta Astronautica*, 84(3-4), 56-68

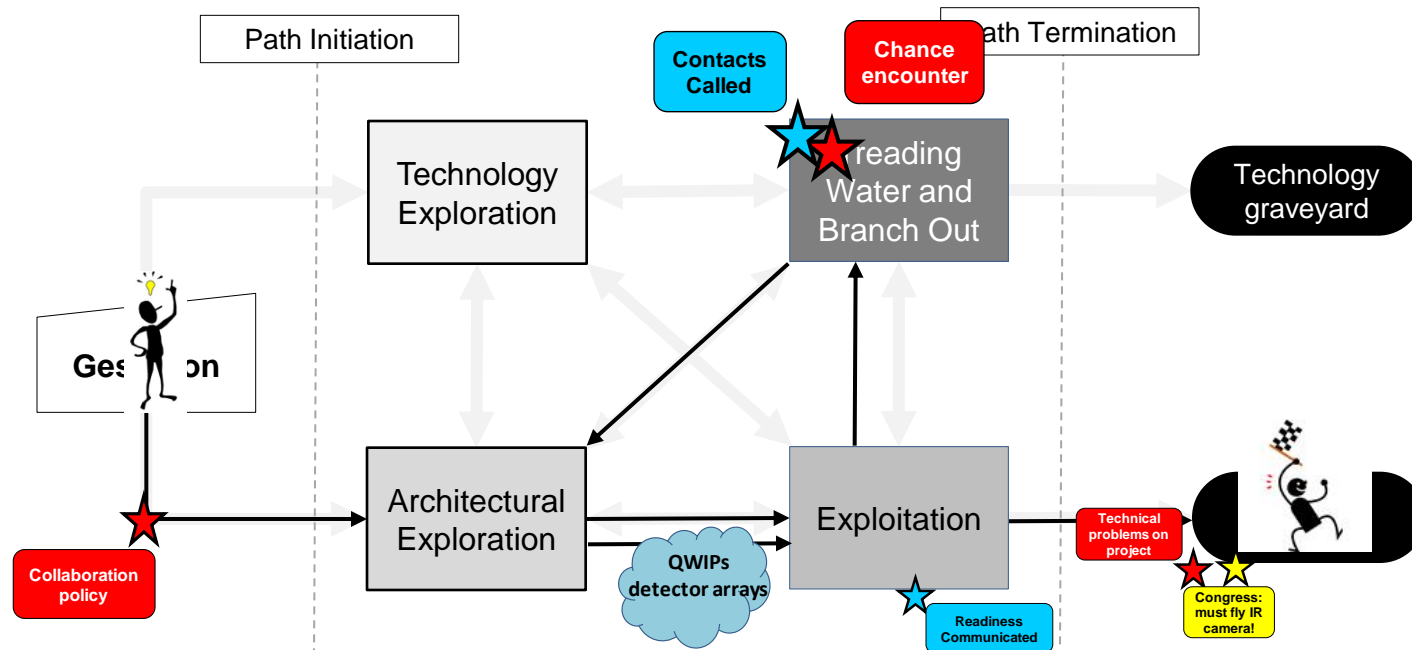
Epoch-Shock Model: Track View

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Epoch-Shock Model: Track View

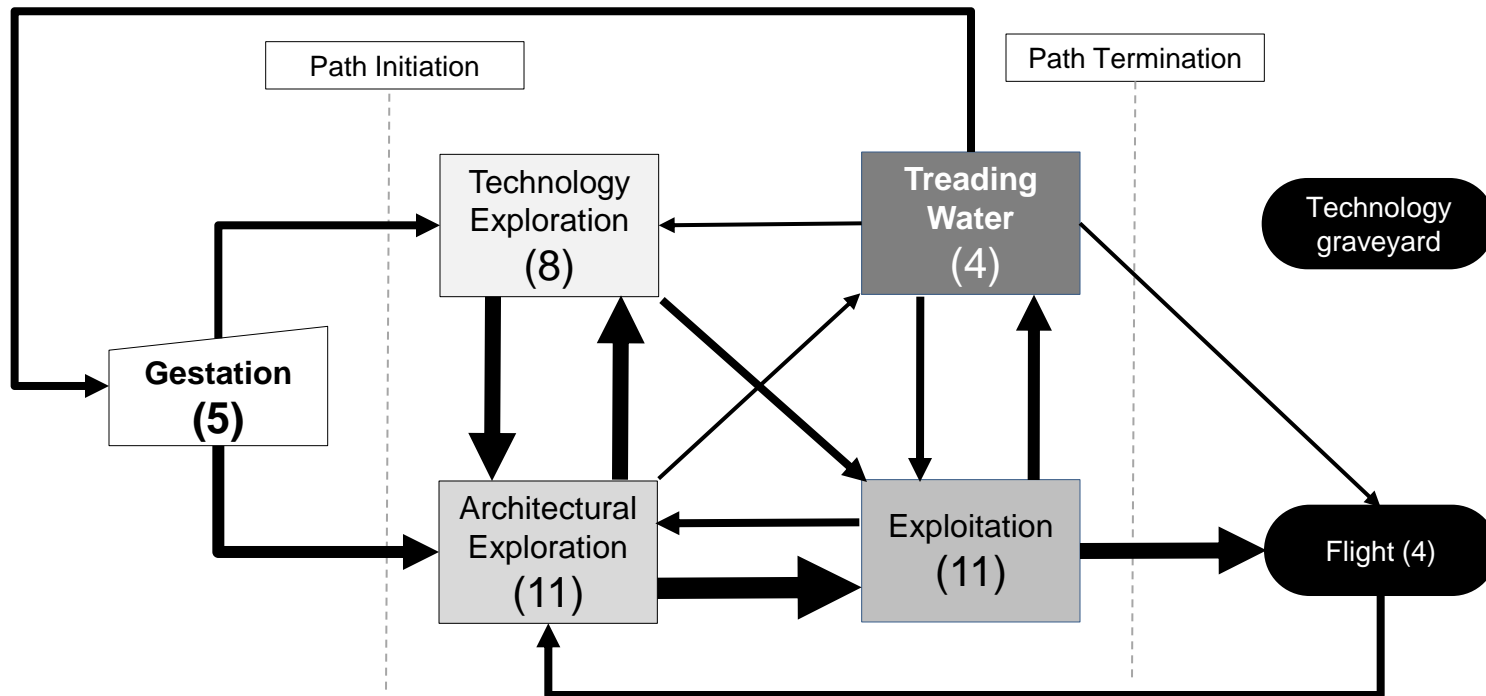
- System exhibits **epochs** of persistent stable (and identifiable) behaviors punctuated by transition inducing **shocks**



- **Epochs** are illustrated as boxes, and roughly map to stages
- **Shocks** induce transitions following arrows from one box to another
- **Innovation pathways** start in gestation and move through the system.

Epoch-Shock Model: Paths Traveled

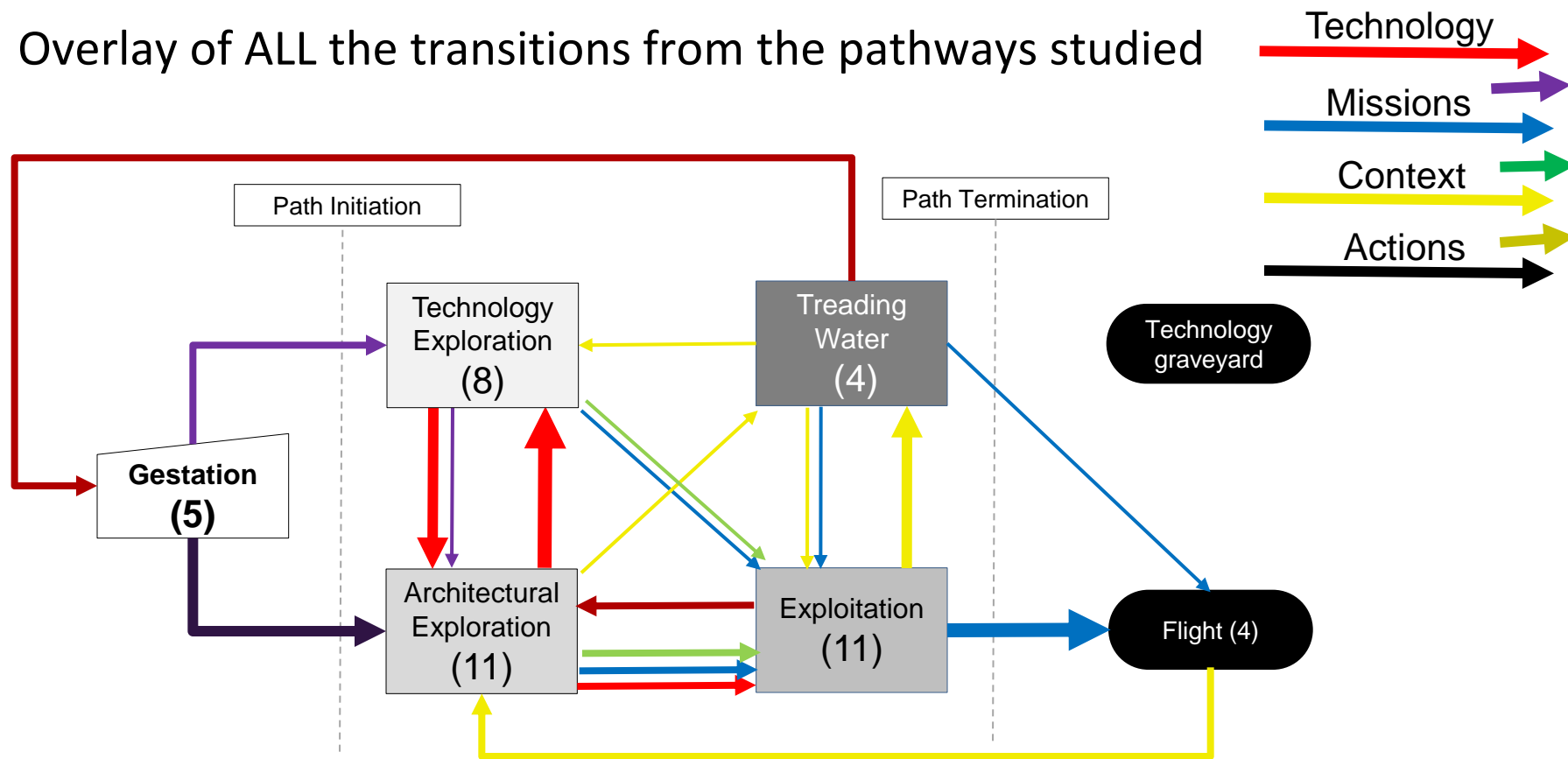
- Overlay of ALL the transitions from the pathways studied



- Bi-directional and heavy flow between Technology and Architectural exploration.
- Flow through Exploitation forks between Treading Water and Flight

Epoch-Shock Model: Paths Traveled

- Overlay of ALL the transitions from the pathways studied

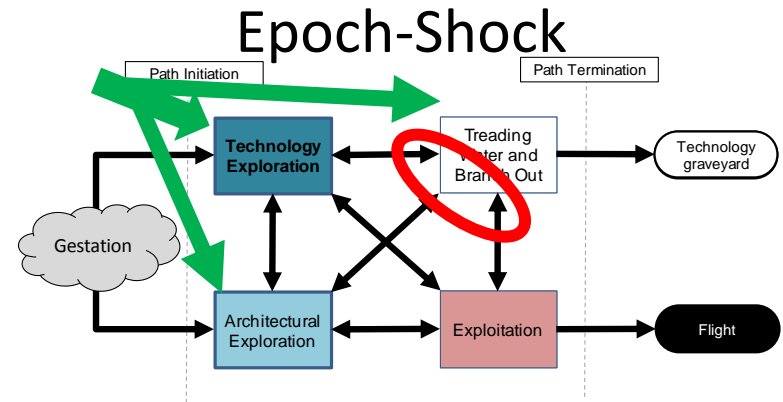
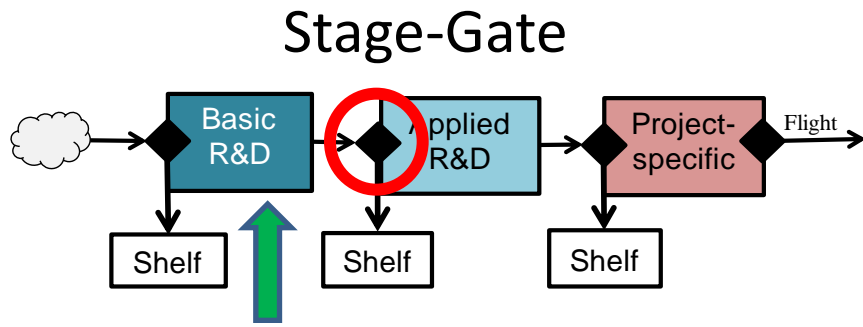


- Colors differentiate different types of shocks, some of which are more controllable by management interventions
- Combined shocks are possible (e.g., red + blue = purple)

Implications:

Stage-Gate-based management strategies suppress important dynamics. The Epoch-Shock view provides a basis for feasible, productive intervention.

Why Stage-Gates Can't Work



Current control mechanisms

- ➔ 1. Proportionally more funding for basic R&D to increase pool of early-stage concepts.
- 2. Used gate decisions to control % progression to next stage.

Assessment based on Epoch-Shock model

- 1. Resources can't be earmarked for "early stage/basic." In practice that funding stream is split between basic concepts and others that are treading water and branching out.
- 2. Actively controllable gates don't exist. Winnowing happens based on the co-timing of a technical breakthrough (unpredictable) and the next relevant mission call (semi-cyclical).

Rethinking the Management Problem

- Basic insight:
 - As long as innovation occurs at multiple technical levels simultaneously, and innovating teams can choose to draw resources from multiple institutional levels
 - Current management strategies can't work as intended!
- Epoch-Shock formulation provides a basis for rethinking the management problem:
 - Some shocks can be harnessed as management levers: exploring predictability and influenceability.
 - The work environment can be designed, to encourage desirable interactions and collaborations: exploring incentive systems and organizational/architectural interactions

Implications for Cost & Schedule Analysts

- A key part of TRL analysis depends on the stage gate model of innovation
 - Thinking in terms of the epoch shock model may help point analysts to more complex nuances that they need to study and evaluate.
- A key part of estimating an individual technology depends on the broader tech ecosystem
 - Our cases showed that funding for these projects came from a variety of funding sources at multiple levels
- The process of technology development takes much longer than expected

Thanks for your attention. Comments welcome.



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**PhD: Amy
Cox**



**PhD: Jason
Crusan**



**PhD: Sam
Marquart**

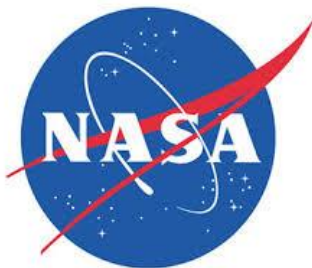


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